BUILDING A MARINE SPATIAL DATA INFRASTRUCTURE TO SUPPORT MARINE SPATIAL PLANNING IN U.S. WATERS

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ABSTRACT

Marine spatial planning (MSP) is emerging as a practical process to help achieve the ecological, economic, and societal objectives of U.S. ocean management. Coastal and ocean data have unique challenges that need to be addressed. Ambulatory boundaries, 4-D data needs, and difficulty acquiring these data in the marine environment are some of the challenges not traditionally faced by land-based planners. To realize the full benefits of MSP, the process will require accurate and authoritative geospatial data from all sectors. Since MSP is an ecosystem-based approach, data are required at various resolutions. "Best available" and "science-based" data are often stated as necessary, but not often defined. How the MSP process will be implemented in the U.S. remains to be seen, but significant work has already begun on developing a national marine spatial data infrastructure (MSDI) for the U.S. This paper discuses the history, institutional and technological challenges, and ongoing development of the U.S. MSDI.

***Index Terms*—** marine spatial planning, marine data, marine spatial data infrastructure

1. INTRODUCTION

Demand for ocean space is outstripping the current policy frameworks designed to manage how humans use the marine environment. In response, marine spatial planning (MSP) processes are being used around the globe to replace fractured single-sector approaches to management. The new processes attempt to ensure that the ecological and socioeconomic services that oceans provide and that societies depend upon, are protected for future generations [1]. Sound MSP, however, requires the availability and analysis of timely geospatial data originating from credible sources. An evolving effort to build a marine spatial data infrastructure (MSDI) is tackling the complex challenges associated with providing authoritative geospatial data for the U.S. across a suite of data themes.

Since the early 1990s, the primary focus of U.S. national spatial data infrastructure has been directed toward terrestrial themes, leaving marine data largely underdeveloped. The rapid increase in interest in MSP is uncovering this issue resulting in more attention from a broader audience. There has been incremental progress on the core cadastral data that constitute the foundation of the MSDI (i.e., jurisdictional boundaries and limits). More complex data themes with less well-defined or, in some cases, nonexistent spatial attributes and legal foundation are currently being developed for incorporation into the MSDI framework (i.e., georegulations, marine habitat and biodiversity, human use, and geology and seafloor). These data are crucial to the success of MSP as is shown by their inclusion in planning efforts in U.S. states like Massachusetts, Rhode Island, and Oregon, following the use of analogous data in efforts on the international stage in countries like Belgium, the Netherlands, and Germany [2].

The objectives of this paper are to describe the key data themes of the MSDI, the progress to date, and complexities and challenges associated with each. The paper will also detail some applications of these data and outline the next steps needed to continue moving the MSDI forward in support of the shifting paradigm in ocean management that is manifesting itself in MSP processes.

2. BACKGROUND

A number of activities have shaped the current thinking on what constitutes the MSDI. In 1990, the U.S. Federal Geographic Data Committee (FGDC) was created and charged with developing a national spatial data infrastructure for the U.S. with much of the emphasis focused on terrestrial data themes [3].

In 1999 the National Oceanic and Atmospheric Administration (NOAA) led the development of the

first regional ocean planning information system and began to systematically address MSP data issues and requirements [4]. Data were found to be sparse or nonexistent, primarily because of the technological limitations of acquisition. A primary marine data source, the official nautical chart, was not easily adaptable to MSP needs. Standards developed for land (i.e., cadastral) didn't address all aspects of marine data. Data were spread across multiple agencies and not often accessible.

To address these issues, the FGDC Marine Boundary Working Group was established in 2001 [www.csc.noaa.gov/mbwg]. This federal work group provides a venue for communicating about and coordinating marine and coastal geospatial issues such as standards, partnerships, and access. The group began systematically working through federal geospatial data and related policy issues needed to support the MSDI. Federal agencies with offshore responsibility represent a broad spectrum of traditional (i.e., navigation, fishing, and energy) and nontraditional (i.e., radio spectrum) ocean uses are included in the work group. In addition, because U.S. territorial waters encompass individual coastal states, work started soon after to coordinate better across state and federal jurisdictions.

The Energy Policy Act of 2005 accelerated the development of the MSDI. The act mandated the development of a mapping system to support alternative energy planning on the U.S. outer-continental shelf. In direct response to the act, the FGDC Marine Boundary Working Group coordinated the development of a mapping system called the Multipurpose Marine Cadastre (MMC)[1]. The significance of using the term "cadastre" in U.S. policy is that it gives MSDI data development an additional requirement to ensure data are from authoritative or trusted government sources. This formed a fundamental operating tenet of the work that followed on the MSDI.

On December 14, 2009, President Obama's Interagency Ocean Policy Task Force released its Interim Framework for Effective Coastal and Marine Spatial Planning for review, which offers a comprehensive, integrated approach to planning and managing uses and activities [5]:

> "Under the Framework, coastal and marine spatial planning would be regional in scope, developed cooperatively among Federal, State, tribal, local authorities, and regional governance structures, with substantial stakeholder and public input."

The data needed to support MSP reside within a heterogeneous community across government and scientific organizations. To make effective use of these varied data sources, regional and federal partners must collaborate to identify priorities, employ mechanisms to integrate compatible data, manage quality, and enable exchange of spatial information using consistent techniques. To address this need, the task force called for a national information system to establish and implement consistency in data products. This guidance from the task force focuses even greater attention on the evolving MSDI and greatly influences data priorities, processes, scales, and access.

3. DATA THEMES

"Improved decision-making", "ecosystem-based", science-based," "best-available", and "managing human activities to reach societal goals", all are terms that have been used to describe requirements for MSP data. The reality is that all geographic data are an abstraction of reality. Trade-offs have to be made in data development, updates, resolution, and in the techniques for presenting the data. Since MSP is a continuous process [6] the goal for developing the U.S. MSDI is to begin with fundamental data and to increase the complexity and accuracy over time as requirements become better understood.

The data are currently divided thematically into the supporting areas of jurisdictional boundaries and limits, federal georegulations, navigation and marine infrastructure, geology and seafloor, habitat and biodiversity, and human use. Each theme has its own unique challenges (addressed below) but the following operating tenets apply broadly across the themes:

1. Data are issue-neutral and should be able to be viewed and queried as necessary to support decision-making.
2. Efficient electronic access to data should be provided using well-described formats that can be broadly assimilated by stakeholders.
3. A foundation of authoritative and trusted data sources should come from agencies with legislative mandates or responsibility for data.

[1] Similar to the nation's land-based parcel system, a marine cadastre describes the spatial extent, rights, restrictions, and responsibilities of U.S. waters.

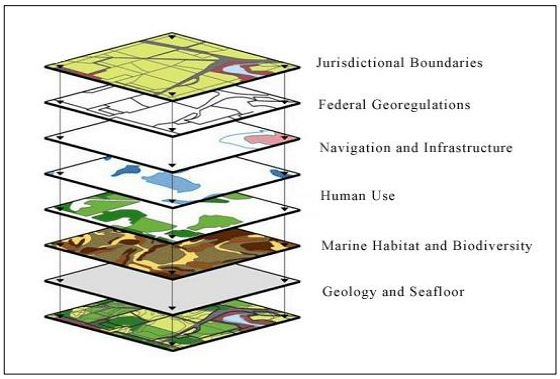

Figure 1. Marine Spatial Data Infrastructure Themes

4. Data should be served from as close to the source agency as technologically possible. Vision is that all data will eventually be served at source using Web service[2] technology.
5. Data must have FGDC-compliant metadata.
6. Data should be built on national or international standards where they exist.
7. Data have value across multiple issues and jurisdictions and should be created once and used as many times as needed.
8. Data life cycle should prescribe update process but not wait for data to be perfect. Build on existing data and improve over time.

3.1 Jurisdictions Boundaries and Limits

In the MSDI, jurisdictional boundaries and limits refers to the set of data defining areas or zones managed for official purposes. This includes the internationally recognized limits such as those specified by the United Nations Convention on the Law of the Sea (UNCLOS), including the Territorial Sea and Exclusive Economic Zone (EEZ), to more local zones such as marine sanctuaries or parks.

Marine jurisdictions are similar to their land-based counterparts in that, in order to map the boundary, the law must be interpreted in a spatial context [4]. Where the marine environment diverges is that marine boundaries generally have no demarcation or physical evidence to mark the space (e.g., monument, pin, or fence). As GPS technology evolves, the delimitation of the marine boundary is becoming more accurate, but the challenge lies where the "old world" mapping meets the "new world." Regulations and laws refer to these old boundaries and the MSDI is working to reconcile differences.

For example, historically the U.S. territorial limits were mapped to reflect the relatively straightforward technology of the times – the 3-mile distance that a cannon ball could be fired. Today, UNCLOS uses terminology to define jurisdictions, such as a tidal datum of mean high water (MHW). The lines sound plausible until an attempt is made to create them digitally. MHW is the average of all the high waters over a 19-year cycle. Even though tide gauges are extremely accurate in measuring MHW at a point location, the entire length of shoreline is still a modeled value. The ambulatory nature of official boundaries like MHW has a ripple effect all through the development of data for MSP. With changing sea level, it becomes even more important to develop the MSDI in a way that accommodates ambulatory data.

Why should the MSDI care about exactly where a boundary like MHW is located? Jurisdictions and regulations are tied to the lines, and ultimately, money and activities are allowed or denied based on these boundaries. Recently, the first offshore wind energy permit in the U.S. was held up as the line between state and federal jurisdiction (tidal datum) was determined. The transition to clearly define boundaries with coordinates cannot happen overnight, but the MSDI must facilitate access to the latest and most accurate data, continue to facilitate partnerships that improve data and reduce conflicts, and encourage projects that document best practices for offshore data development [7].

3.2 Georegulations

In MSP, much attention is applied to geospatial data development of physical and environmental components, but the legal regime is an often-overlooked and equally important regime to represent in the process. In context with other resource data, the regulations, laws, and management structures help decision makers understand ocean use conflicts and compatibilities. To accomplish this spatial analysis requires a defined geography of the regulation data layers in a form suitable for use in GIS.

[2] Industry standard web services allow different applications to utilize each other's data independent of software or operating system utilizing XML. Federal agencies are implementing web services to support national geospatial mandates, but institutional and IT security challenges still exist requiring interim system approaches for providing data access.

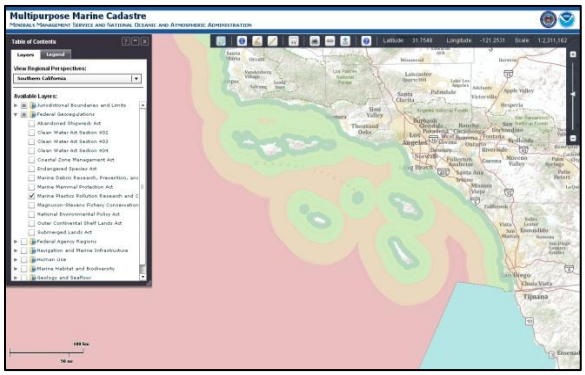

Figure 2. Georegulation of the Marine Plastics Pollution Research and Control Act.

Once developed, georegulations can be a valuable part of the MSDI and contribute to the broader MSP process. Creating georegulations involves researching the federal and state policy framework in the area of interest and creating spatial "footprints" of the geographic area where individual policies apply. The development of a georegulation requires careful scanning of the text for any geographic reference. This could be something as easy to map as defined latitude and longitude to something more challenging such as “all navigable waters” Because policy makers, not geographers, generally write regulations, the challenge is to adequately capture the geography intended by each individual law. Georegulations offer the ability to visualize the spatial extent of regulations and analyze intersections with other data layers. Georegulations are often built on jurisdictional boundary data and therefore must reflect the best practices of these underlying data. When added to the MSDI, these data bring the ability to more easily visualize compatibilities and inconsistencies in federal or state policy.

3.3 Navigation and Marine Infrastructure

Navigation and marine infrastructure data are considered baseline information for any marine-related application. This theme consists of common navigational and infrastructure data such as shipping lanes, fairways, wrecks and obstructions, and oil platforms. Planners in the marine environment need to know where these data exist in order to avoid potential conflicts. The official U.S. nautical chart is developed to support safe navigation and have a known navigation or “shoal” bias inherent in its production[3]. [8] Building this theme as part of the MSDI presents several unique challenges, the most notable being that the data are organized by individual chart geography across multiple scales. Ideally, to construct a seamless navigation and marine infrastructure theme for the U.S., data would require reconstruction from source data. This is a painstakingly detailed task of determining which agency collected the original chart information. U.S. chart data are becoming more broadly available in the Electronic Navigational Chart (ENC) format[4] but are still not specifically designed for MSP and extensive manipulation.

Another important data set in this theme is the one that represents true vessel locations termed Automated Information System (AIS) data. Transponders on ships send signals picked up by receivers on land used to track commercial vessel movement in U.S. waters. AIS data are proving vital to MSP efforts, as demonstrated in the Massachusetts Ocean Plan, and provide a more realistic view of commercial shipping ocean use than traditional chart products [9].

3.4. Marine Habitat and Biodiversity

Application of spatial data to describe and characterize the complexity of marine ecosystems is essential to implementing MSP. Ecosystems and the services they provide need to be represented in a way that supports the MSP process of considering ecological and socioeconomic objectives in concert. Multiple approaches to assessing ecological or biological values of marine areas have been developed and applied to MSP efforts [9, 10]. The availability and quality of these data, however, vary greatly across regions, creating challenges for development of the MSDI for marine habitat and biodiversity.

Unlike boundaries that are relatively consistent across geography, biology is intimately tied to local conditions. For example, many of the key habitats and species that would be relevant to a specific planning scenario in the Northeastern U.S. do not exist on the West Coast. This reality confounds the thought process surrounding which data are logical to include when describing habitat and biodiversity at a national scale. Additionally, there is no single classification scheme accepted by the U.S. government for marine habitat that provides a

[3] Charts must portray any known bottom feature shallow enough to present a hazard to shipping but do not need to indicate any deeper aspects of the bottom

[4] ENCs are built to an International Hydrographic Office (IHO) specification called S-57.

framework to support visualization of these data at a common level across the U.S.

To deal with these challenges and realities associated with nascent MSP efforts, the approach to building marine habitat and biodiversity data into MSDI is to use habitat and species designations associated with laws like the Endangered Species Act and the Magnuson-Stevens Fisheries Conservation and Management Act. This approach is in keeping with the legal-responsibilities information conveyed in the core marine cadastral data. Users can determine which of these authoritative data sets are relevant to their specific MSP process.

3.5 Geology and Seafloor

The MSDI includes bathymetric contours, undersea place names, physical substrate sample locations, and sediment grain size distribution maps. These data apply to everything from the basic need to know water depth, to more complex issues like correlating physical characteristics of the seafloor to habitat for species of concern. These data are essential to multiple steps in MSP processes, but challenges like limited availability or access, and lack of consistency in data products, present obstacles to their inclusion in the MSDI.

Many of the publicly available geology and seafloor data sets with large coverage areas are of insufficient resolution to support MSP at the scale with which it is occurring, or are derived from data that are decades old. Remote collection of marine geology and seafloor data are more costly than the terrestrial equivalent, which can be done with aircraft or satellites. Advances in technology have closed the gap, but highly accurate surveys on land have been conducted for a longer period than those focused on the bottom of the ocean. Energy exploration and national security needs have both resulted in a large amount of data that are often unavailable to the public, and therefore, to support MSDI development either.

Strong partnerships need to be fostered between government agencies and offices that may not have traditionally collaborated. To benefit the users of geology and seafloor data, the MSDI should consider the state and regional data needed to support decision-making at these scales where MSP in the U.S. is most likely to continue occurring. Compiling and serving spatial footprints and essential attribute information for existing geology and seafloor data, similar to the georegulation approach, would be a valuable addition to the MSDI. This approach will allow users to determine if information exists in areas they are interested in. This will also keep the responsibility of data maintenance and storage with the providers, allowing the MSDI resources to be focused on other needs.

3.6 Human Use

There is general agreement that understanding human use patterns in the ocean is important to making informed management decisions. However, there is very little spatial information available on human uses, especially in comparison to other complex data themes like marine habitat and biodiversity [11]. Human uses can be broken down into broad categories like commercial and recreational fishing, industrial and military and non-consumptive (i.e., paddle sports, scuba diving, recreational boating, etc.).

Considering where humans are using the ocean and what areas and resources they are depending on is critical to making transparent and informed management decisions supported by the public [12]. The challenge inherent in pursuing this ideal is a general paucity of data that depict human use patterns in our oceans both current, and historical. Similar to the case of the geology and seafloor data theme, collecting human use data often requires resource- and time-intensive methods of surveying users directly or via the Internet. Since many recreational activities do not require any kind of permit or registration, users can be difficult to locate and contact for data collection.

There are efforts to address this lack of human use data for specific initiatives in the U.S. The California Ocean Uses Atlas project [mpa.gov/dataanalysis/atlas] and Open OceanMap tool [www.ecotrust.org/ocean/OpenOceanMap.html] are both good examples. These efforts are focused on addressing specific needs related to local initiatives, however, and do not contribute directly to the larger national-level MSDI needs. The data that presently populate this theme are associated with energy leases and sand and gravel extraction areas. More work is needed to ensure that efforts undertaken to increase our understanding of human activities in the ocean produce spatially explicit results that support mapping and monitoring.

5.0 NEXT STEPS

Efforts to uncover and address issues associated with jurisdictional boundaries and limits, development of methods and data for georegulations, and compilation of marine navigation and infrastructure data for MSDI all support current MSP processes and can be visualized through MMC. The work to unravel the complexities associated with the geology and seafloor, marine habitat and biodiversity, and human use data themes is just beginning. Strengthening the balance of the MSDI themes to increase their utility to evolving MSP processes in the U.S. requires several areas of focus:

- MSP in the U.S. is moving forward at regional and sub-regional scales. Future MSDI efforts must consider development of data sets and viewers that take advantage of locally available higher-resolution and more timely data that support MSP efforts at the scale at which they are occurring.
- Realizing the full potential of MSDI requires addressing the challenge of portraying uncertainty associated with spatial data. Since all data model reality, it is important to find ways to convey how close to reality the depictions of various data sets are.
- MSDI must be able to integrate the best science available to describe the complex multidimensional aspects of ecosystem processes and, in turn, inform science about the gaps needing attention.
- The level of complexity inherent in the data themes discussed here requires there to be multiple data products in the MSDI that address issues specific to individual data types. Issues like standardization, authoritative sources, and user needs are still being resolved for the more complex data and will continue to shape the evolving MSDI.

A great deal of progress has been made building the current MSDI. Continued work on the issues outlined here will ensure that the full potential of these vital data resources for advancing MSP is realized.

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